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Comparative analysis of engine generator performance using diesel oil and biodiesels available in Paraná State, Brazil

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ABSTRACT

Biodiesel is an alternative energy source used in internal combustion engines (ICE), as a replacement for diesel oil. In general, the farming and livestock activities can be used to obtain biomass sources for bioenergy production. Several raw materials (fatty acids sources) obtained from renewable sources can be employed to biodiesel production, providing biofuels with distinct physicochemical properties. Also, in Paraná State, Brazil, products such as soybean oil, sunflower oil, beef tallow, and chicken fat are used for biodiesel manufacturing. Thus, this work aimed to evaluate the engine generator performance using biodiesels obtained from soybean, sunflower, chicken fat and beef tallow compared to mineral diesel. The tests were performed using an engine with power of 7.36 kW on an electric generator with power of 5.5 kW. In engine load simulation, it was used as resistor bank, being the power generation selected on dashboard controller in the following sequences: 1.0 kW, 2.0 kW, 3.0 kW and 4.0 kW. The engine generator performance was evaluated by specific fuel consumption (SFC) and efficiency (η). In general, the engine SFC using biodiesels was higher, when compared to diesel oil. However, the overall efficiency of engine generator with biodiesels was higher, with gain of up to 2.0%. Among the biodiesels compared to diesel oil, the best results for engine generator performance were obtained, respectively, from sunflower and soybean oils, due to lower increase in the SFC (7.6%) and slight increase in the overall efficiency.

Contents

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1. Introduction

1.1. Biodiesel in diesel cycle engines compared to diesel oil

The biodiesel manufacturing can be performed using several raw materials (unsaturated or saturated fat sources). In Brazil, common sources for biodiesel production are soybean, beef tallow, sunflower, flaxseed, chicken fat, jatropha, palm, cotton, crambe, castor bean and domestic wasted oils, among others. The biodiesel characteristics generally are in accordance with raw material, resulting in slight physicochemical differences for each biofuel. So, the National Agency for Petroleum, Natural Gas and Biofuels (ANP) from Brazil, published the resolution no. 7 in 2008, to define the physicochemical parameters of biodiesel. In general, it has been observed that biodiesel has Lower Heating Value (LHV), higher viscosity and density, when compared to diesel oil.

The biodiesel is generally used in the internal combustion engines (ICE) with diesel cycle, at 100% (B100), or using diesel blends. The ICE performance for diesel cycle using biodiesel, compared to diesel oil, had shown a slight power reduction and increase in the specific fuel consumption (SFC). However, as an advantage over diesel oil, there were identified lower nitrogen oxides (NOx), hydrocarbons and sulfur oxides (SOx) emissions [1]. Others advantages of biodiesel compared to diesel oil are lower smoke emissions and lubrication properties, which can extend engine lifetime [2]. Moreover, biodiesel represents a renewable energy source.

However, the continuous use of biodiesel in engines can cause deterioration of lubricating oil, due to combustion wastes into the chamber and contaminants contained in biodiesel, such as water and silica [3]. The degradation of lubricating oil can increase abrasion of moving parts in combustion chamber. Hence, engine sizing and design for biodiesel shall consider operating conditions, such as deposition of ashes in injectors, cylinder head, and pistons, with early degradation of lubricating oil.

1.2. Potential of biodiesel manufacturing in Paraná State

Brazil, according to Brazilian Institute of Geography and Statistics (IBGE) [4] was considered the 3rd largest broilers producer in the world, and thus, demonstrates a large potential to biodiesel manufacturing from chicken fat. Gomes et al. [5] estimated the potential to biodiesel manufacturing from chicken fat considering the number of broilers slaughtered in five cooperatives located in west of Paraná State. In a survey, it was verified that 1.14 million broilers are slaughtered daily, or 300.96 million broilers annually, generating approximately 77.29 t of chicken fat daily, or 20,405.08 t annually. On the estimated of potential to biodiesel manufacturing, it was considered that 95% of chicken fat are converted into biodiesel, thus, resulting in 73.95 t daily, or 19,525.20 t annually. In Paraná State, the number of broilers destined to slaugh in 2011 was 1.40 billion [6].

Despite the renewable source potential, the chicken fat biodiesel in Brazil represented only around 0.04%. Currently, the largest sources used to manufacturing biodiesels are, respectively, soybean oil (71.13%), and beef tallow (18.66%). In Brazil, the biodiesel manufacturing doubled in the years 2008–2011, being produced nearly 2.65 million m^3 in 2011. On the same year, the daily capacity of biodiesel manufacturing in Paraná State was 479 m^3, and the next years the daily capacity shall be increased to 2006 m^3 per day [7]. During 2010–2011 season, the soybean crop in Brazil was 75.3 million tons, being 15.4 million tons of that from Paraná State [8]. Among biodiesel manufacturing sources in Paraná State, the sunflower is commonly used to crop rotation, as an alternative to soil conservation and crop diversification on farming.

Fiorese et al. [9] analyzed the manufacturing cost for biodiesels from soybean, sunflower, beef tallow and chicken fat. The simulation cost was performed for a small biodiesel energy mill valued at R$ 180,000.00 (~US$ 90,000.00), located in Cascavel, in Paraná State, with production capacity of 0.9 m^3 per turn (8 h). The raw materials costs were obtained considering acquirement performed nearby the mill (less than 150 km). The most significant variable in biodiesel price was the differences of raw materials cost, beyond others relevant inputs, such as energy (electricity and firewood), methanol and sodium hydroxide. The lowest prices were obtained, respectively, to biodiesels from beef tallow (R$ 2.01 L^{-1}~US$ 1.0 L^{-1}), chicken fat (R$ 2.20 L^{-1}~US$ 1.1 L^{-1}), soybean (R$ 3.23 L^{-1}~US$ 1.62 L^{-1}), and sunflower (R$ 3.34 L^{-1}~U$$ 1.67 L^{-1}). Thus, beef tallow biodiesel showed greater economic viability when compared to others analyzed biofuels.

Nowadays, diesel oil has an economic advantage over biodiesel acquisition. However, biodiesel production and consumption are important means to improve energy security through energy matrix diversification. Moreover, it is a renewable energy, contributing to environmental conservation. This work aimed to perform a comparative analysis of engine generator performance using diesel oil, compared to biodiesels (B100) available in Paraná State, including biodiesels from soybean, sunflower, chicken fat and beef tallow.

2. Materials and methods

The performance tests were performed using an engine generator set, model BD 6500CF, Branco brand, mechanical power of 7.36 kW (10cv), generator of 5.5 kVA (5.0 kW) rated power, and monophasic alternator with output voltage options of 120/240 V. The biodiesels were acquired from a mill located in Cascavel, in Paraná State, with biodiesel production capacity of 0.9 m^3 per 8 h (work turn).

The diesel ICE tests were performed using biodiesels from representative sources in agro-industries in west of Paraná State, such as biodiesels from soybean, sunflower (unsaturated fatty acids), chicken fat and beef tallow (saturated fatty acids). The biodiesel manufacturing was performed through transesterification process, by methyl route, and alkaline catalysis with sodium hydroxide (NaOH) to accelerate reaction. In biodiesel manufacturing, it was added methanol ($CH3OH$) at a proportion of 20%. The feedstock quality was analyzed through acid level, expressed as the percentage of oleic acid, resulting in less than 3%. Therefore, the methanol catalyst (which depends on the oleic acid level) was used at the same amount for manufactured biodiesels.

2.1. Specific fuel consumption determination

To establish the engine generator fuel consumption, it was used an external storage tank placed on a precision balance, and a digital timer to verify the fuel mass flow on the engine generator set during performance tests. The fuel mass flow was computed using the following equation:

$$\dot{M} = \left(\frac{(Mt+Mi)-(Mt+Mf)}{t} \right) \quad (1)$$

$\dot{M}$	fuel mass flow, kg s^{-1}
Mt	storage tank mass, kg
Mi	fuel mass at begin, kg
Mf	fuel mass at end, kg
t	test time, s

In order to determine engine generator performance, a resistor bank was used for load simulation, selecting the generation powers in dashboard controller, in following sequence: 1.0 kW, 2.0 kW, 3.0 kW and 4.0 kW. The loading cycles were applied for all tested fuels. The loading was performed from lower to higher loads, increasing 1.0 kW through dashboard controller. The engine generator fuel consumption

was studied through specific fuel consumption (SFC), as a function of loading variation in engine generator.

$$SFC = \left(\frac{(3600)(\dot{M})}{(V)(I)} \right) \quad (2)$$

where

SFC specific fuel consumption, g kW^{-1} h^{-1}
$\dot{M}$ fuel mass flow, kg s^{-1}
V voltage, *V*
I electrical current, *A*

2.2. Overall efficiency determination

The fuel calorific value influences the performance of engine generator set, hence it was determined the higher heating value (HHV) of diesel, and biodiesels from soybean, sunflower, and chicken fat, using a calorimeter, E2K model. The calorimeter has a container that was connected to the ignition wire; and maintained the sample under adiabatic condition at 30 atm (3.04 MPa). The fuel samples (0.5 g) were put in the chamber for full combustion, to determine HHV. In cases of incomplete combustion, the samples were ignored. To compare HHV of fuels used on engine, the samples were organized in four randomized blocks (diesel, and biodiesels from soybean, sunflower, and chicken fat) with three replications, using Tukey test for means, with 5% of significance.

HHV represents the energy released in combustion per unit of fuel mass, but it considers also the energy used to evaporate water contained in fuel, which returns to system through condensation process (combustion chamber of the engine). The work performed on the pistons in combustion chamber depends of energy released in fuel during combustion. The lower heating value (LHV) represents the effective energy released per unit of fuel mass, and also the work generated by the water steam on the pistons. According to Volpato et al. [9] the LHV can be described from HHV using the following equation:

$$LHV = HHV - 3.052 \quad (3)$$

in which

HHV higher heating value, MJ kg^{-1}, and
LHV lower heating value, MJ kg^{-1}

In the evaluation of the engine generator set performance, the efficiency can be obtained through lower heating value and specific fuel consumption (Eq. (4)). The efficiency expresses the conversion from chemical energy of fuel to electrical energy in the generator. Therefore, the following equation represents overall efficiency (η) on the engine generator set:

$$\eta = \left(\frac{3600}{(LHV)(SFC)} \right) 100 \quad (4)$$

where

η set efficiency, %
SFC specific fuel consumption, g kW^{-1} h^{-1}
LHV lower heating value, MJ kg^{-1}

3. Results and discussion

3.1. Specific fuel consumption of engine generator

In general, the tests using biodiesels (B100) in the engine generator set showed increase of SFC when compared to diesel oil (B0) (Fig. 1). As exceptions, biodiesels from soybean (881.87 g kW^{-1} h^{-1}), sunflower (863.1 g kW^{-1} h^{-1}), and beef tallow (917.43 g kW^{-1} h^{-1}) showed smaller SFC when compared to diesel oil (1009.7 g kW^{-1} h^{-1}) at 1.0 kW nominal load. The highest SFC was obtained for chicken fat biodiesel. The peak was 625.26 g kW^{-1} h^{-1}

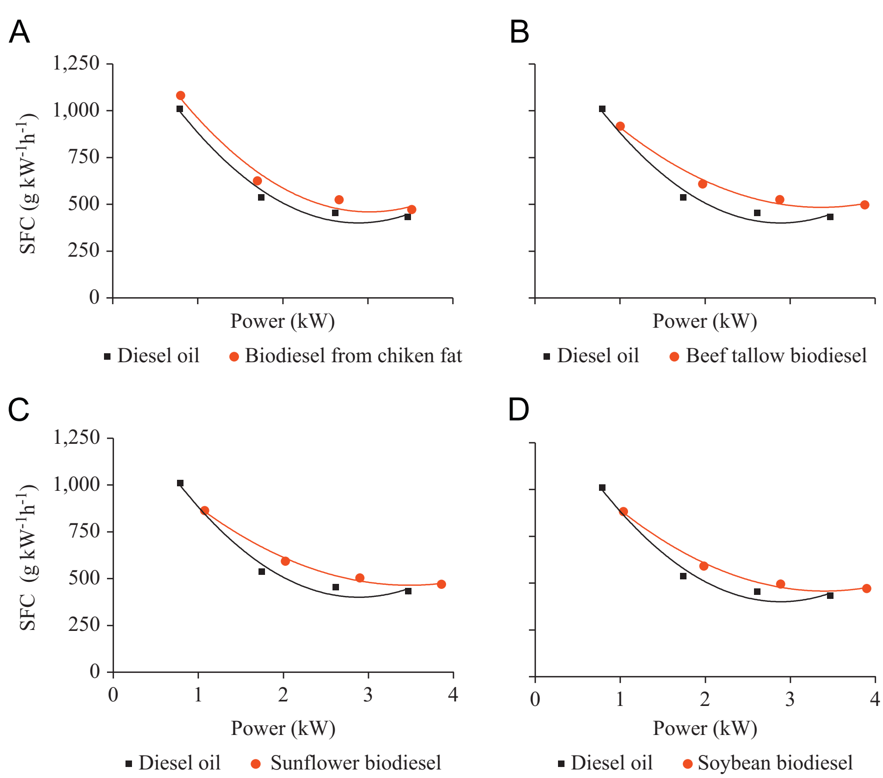

Fig. 1. Specific fuel consumption in the engine generator set using biodiesels and diesel oil.

on 2.0 kW load, that is 23.6% greater than SFC-B0 (diesel), that equals to 505.73 g kW^{-1} h^{-1}.

The SFC of soybean biodiesel was similar to that of diesel oil. At 1.0 kW load, it was observed a reduction of 12.7% in the SFC, when compared to diesel oil. Volpato et al. [10] obtained also similar results using soybean biodiesel blends on the diesel engine, at power of 75 HP (56 kW). However, it was obtained decrease of 14.66% of engine SFC.

Fig. 1 shows the SFC of the engine using four kinds of biodiesels compared to diesel oil. It can be observed the load range, the SFC variations, and differences of SFC in the engine. It can be observed a higher consumption level for biodiesels in the engine generator set. According to Ferrari et al. [11], biodiesel blends at proportions above 20% provide increase of SFC in the engine, when compared to diesel oil, and an increase of 13.4% was obtained using B100. Rageman and Phadatare [12] performed evaluation on diesel engine under biodiesel blends with karanja oil (*Pongamia glabra*) and diesel oil. Thus, it was observed that proportions up to 40% of biodiesel did not increase the smoke density level and carbon monoxide, besides having SFC similar to diesel oil.

Fig. 2 shows the average increase of engine SFC using biodiesels compared to diesel oil, with highest level obtained for biodiesels from chicken fat and beef tallow, respectively, which were produced from fatty acids sources. The SFC of chicken fat biodiesel compared to SFC-B0 was 16.2% higher on average. This result was similar to that obtained by Soranso et al. [13] for engine performance using waste frying biodiesel in a tractor with 73.6 kW (100 hp) engine power. In this case, it was verified an increase of 18% on average, when compared to diesel.

It can also be observed that SFC has increased when soybean and sunflower biodiesels were used, although at lower level (Fig. 2). For both fuels, it was verified an increase of 7.6%, when compared to diesel oil. Corrêa et al. [3] obtained similar results for a 46.0 kW (75 hp) engine using sunflower biodiesel (100%), verifying a SFC increase of 7.3%.

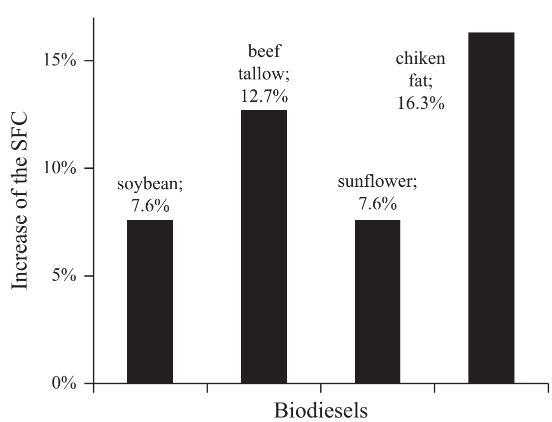

Fig. 2. Comparison of the SFC using biodiesels related to the diesel oil.

Table 1
Calorific value of fuels.

Biodiesel samples ($MJ\ kg^{-1}$)				Average*
Soybean	40.26	38.97	39.07	39.43a
sunflower	38.37	39.12	39.04	38.85a
Chicken	38.13	39.72	37.47	38.44a
Diesel	43.83	43.50	45.27	44.20b

* Means that are followed by the same letter are similar by Tukey test, with 5% of significance ($P < 0.05$).

The higher biodiesels SFC was mainly caused by smaller LHV, when compared to diesel oil. According to Castellanelli et al. [14], the viscosity differences between biodiesel and diesel oil can be an important factor for engine performance due to poor atomization into the combustion chamber, resulting in incomplete combustion, under low and medium speeds. The differences of fuel densities can also affect engine generator SFC, since injectors apply constant volumes in considered loads, but with different masses [15,16].

3.2. Calorific value

Table 1 shows the lower heating value (LHV) for biodiesels from soybean, sunflower and chicken fat, which are similar among themselves, but different to diesel oil, under significance level of 5%. The LHV of soybean biodiesel (39.43 MJ kg^{-1}) compared to diesel oil (44.20 MJ kg^{-1}) was 10.8% lower, confirming the results described by Qi et al. [17] that evaluated engine performance using biodiesel from soybean and diesel oil. In this case, the LHV of biodiesel (38.81 MJ kg^{-1}) was comparatively 10.2% lower than the diesel oil (42.50 MJ kg^{-1}).

3.3. Overall efficiency of engine generator set

In general, the engine generator performance showed higher SFC level and lower efficiency level for the loads smaller than 2.0 kW, and, in the other cases, for loads greater than 2.0 kW, it showed lower SFC level and higher efficiency level (Figs. 1 and 3). However, biodiesels promoted a slightly efficiency increase, even on loads smaller than 2.0 kW, compared to the diesel oil. According to Panwar et al. [18] the slightly higher performance may be due to more concentration of oxygen molecules in biodiesels (esters methyl),what may assist combustion, especially on smaller loads (smaller than 2.0 kW at the presented situation), when the air aspiration decreases in engine.

The maximum overall efficiency for the engine generator set was obtained on 4.0 kW load, what was observed for all fuels. In this nominal load, when diesel oil was used, the obtained efficiency was 18%. In general, among the used fuels, the higher efficiency level was 19.75% for sunflower biodiesel. A similar result was obtained using soybean biodiesel (efficiency of 19.52%). The results corroborate those of Silva et al. [19] that used an engine generator (5.0 kW) with chicken fat biodiesel (B100). In their work, it was verified a slightly better efficiency for biodiesel, when compared to oil diesel under higher loads.

The overall efficiency gains for engine generator set using biodiesels were about 2%. Barbosa et al. [20] evaluated efficiency of a diesel engine with 58.2 kW (78 HP) using biodiesel (B100), and observed an average engine efficiency gain of 4%, when compared to diesel oil. In summary, the best performance results of biodiesel for electric generation with engine generator were obtained using biodiesels from soybean or sunflower.

4. Conclusion

In general, the biodiesels from soybean, sunflower, chicken fat and beef tallow used in the engine generator may replace diesel oil without major losses. Therefore, the comparative analysis indicated that main renewable sources for the biodiesels in Paraná State could be used as an energy alternative source for engines with diesel cycle, without major differences to diesel oil, contributing to energy matrix diversification in Brazil.

However, the specific fuel consumption (SFC) of engine using biodiesel was higher than that of diesel oil, mainly because of smaller low heating value (LHV). The largest differences of biodiesel specific

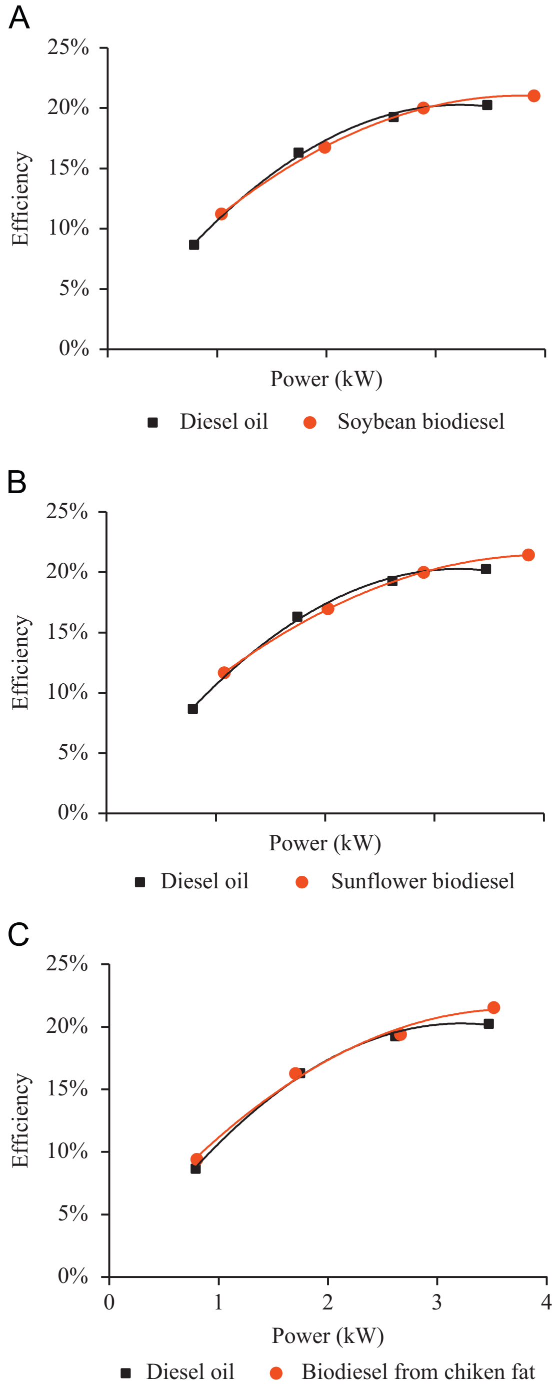

Fig. 3. Overall efficiency of the engine generator set.

fuel consumption, compared to diesel oil, were obtained for biodiesels from chicken fat, beef tallow, sunflower, and soybean, respectively.

The engine generator performance showed lower overall efficiency (η) on smaller loads (smaller than 2.0 kW) due to higher specific fuel consumption level, thus obtaining the highest overall efficiency with lower specific fuel consumption level. In a comparative analysis of biodiesels and diesel oil, it was verified a slightly better overall efficiency for biofuels. The best results of engine generator performance using biodiesels were obtained from sunflower and soybean oils, respectively, due to lower increase in the SFC and slight increase in the overall efficiency.

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